# Results of Vertical Tests with 700-MHz 5-cell (b=0.64) Superconducting Cavities Developed for APT

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***Abstract***

Results of vertical tests for β=0.64 700-MHz 5-cell superconducting cavities developed for the APT project are presented. The APT specification for the cavities requires $Q_0$>5 x $10^9$ at an accelerating field of 5 MeV/m. Six prototype cavities have been manufactured, one at LANL, one at AES (Advanced Energy Systems) and four at CERCA, France. Cavities manufactured at CERCA were named Ayako, Eleanore, Germaine and Sylvia. Three cavities; Ayako, Eleanore and LANL have been tested at LANL and the other three; AES, Germaine, and Sylvia have been tested at TJNAF in Virginia, U.S.A. All the CERCA cavities passed the APT specification and two cavities reached a peak surface field of 41 MV/m (accelerating field is 12 MeV/m and peak magnetic field is 835 Oe). All these four cavities showed field-emission onset around 30 MV/m, which might be related to a multipacting band. Also, there has been a measurement difference in quality factor by nearly a factor of two between the cavities tested at LANL and TJNAF, the cause of which is under investigation. This paper concentrates on the results of CERCA cavities since other cavities have slightly different parameters.

## Introduction

Elliptical cavities for low-beta structures have been recently developed at various laboratories for neutron science [1-2], transmutation of waste [3], and rare-isotope facilities [4]. A review of superconducting RF technology for high-power proton linacs was presented in Ref. [6]. For APT (Accelerator Production of Tritium), 700-MHz 5-cell elliptical cavities have been designed for the high energy section (211-1030 MeV) of the proton linac [5]. At an early stage in the development of low-β structures, there was concern about multipacting in the cavity because the cavity walls get closer together as β gets lower. To check this problem, at KEK, one single-cell cavity with frequency 1300 MHz and β=0.45 was made and tested [7]. The result showed a peak surface field of 53 MV/m (peak-magnetic field Hp of 1330 Oe), confirming the feasibility of using elliptical cavities for low-β structures. At JAERI, single-cell cavities and 5-cell cavities with frequency 600 MHz, and β=0.5 and 0.886 were fabricated and tested. At present, the highest peak electric fields they have obtained are 44 MV/m (β=0.50) [8] and 51 MV/m (β=0.89) [11] for single-cell, and 23 MV/m (β=0.50) and 31 MV/m (β=0.89) for 5-cell cavities [9]. At Saclay, a single-cell 700-MHz cavity with β=0.65 showed a peak surface electric field of 68 MV/m (Hp=1200 Oe) at 1.7 K [10]. At LANL, single-cell 700-MHz cavities with β=0.48 and 0.64 were made and tested before manufacturing the cavities presented in this paper. The highest peak surface fields were 43 MV/m (Hp=1034 Oe) for β=0.48 and 38 MV/m (Hp=964 Oe) for β=0.64 [12].

**The cavity and preparation for tests**

Table 1 shows some parameters of the cavity. The cavities were named after popular names in the countries from which the niobium material were purchased, i.e., Ayako from Tokyo Denkai, Japan, Eleanore and Sylvia from Teledyne Wah Chang, U. S. A. and Germaine from Heraeus, Germany.

Table 1: Cavity parameters (CERCA)

| | |
|---|---|
| Frequency | 700 MHz |
| β | 0.64 |
| R/Q | 392Ω |
| Geometrical Factor | 149 |
| Epk/Eacc | 3.381 |
| Hpk/Eacc | 69.6 Oe/MV/m |
| Nb thickness | 4.0 mm |

BCP (Buffered Chemical Polish) and HPR (High Pressure Rinse) have been adopted as a regular procedure before testing as well as baking at 150 °C right before cooling down. Tables 1 and 2 summarize the conditions for BCP and HPR, respectively.

At LANL, the cavity is chemically polished at a special facility and transported to a newly constructed clean room (class 100) shown in Fig. 1. Then, it is rinsed by fill & dump 3 to 5 times with 18-MΩcm DI water, followed by HPR and dried overnight. Next all the flanges, an input coupler, a pick-up coupler, and a vacuum valve are assembled. The sealed cavity is then moved to the neighboring area to be set on the insert. Figure 2 shows the cavity set on the insert. Before pre-cooling with liquid nitrogen, the cavity is baked with heating tapes at ~150 °C for 2-3 days, which is normally done on weekends.

Pre-cooling, by filling the outer layer with liquid nitrogen for about 16 hours, cools the cavity down to ~250 K before cooling. It takes 3-4 hours to fill the cryostat to the level required for RF measurements. Then (at LANL), we measure the cavity at 4 K and at 2 K on the next day. At TJNAF, however, the measurement has been done at 2 K only mainly due to the fixed-length driving coupler (at LANL, it is adjustable at both 4 K and 2 K).

Table 2: Conditions for BCP

| Conditions | LANL | TJNAF |
|---|---|---|
| Solution $HNO_3$:HF: $H_3PO_4$ by volume | 1:1:2 | 1:1:2 |
| Flow rate (GPM) | 10-20 | 6-8 |
| Etching rate (μm/min) | ~0.3@4-11 °C | ~1@4 °C |
| Total amount of etched thickness | 16-20 μm typical | 10-15 μm typical |
| Rinse | DI water fill & dump 3-5 times | DI rinse (2 MΩcm), 3 min. |
| Clean room class | Normal room | 1000 |
| Flow direction | One direction from bottom to top | Forward and reverse flow |

Table 3: Conditions for HPR

| Conditions | LANL | TJNAF |
|---|---|---|
| Pre-rinsing | Fill & dump 3 times | |
| Water | 18 MΩ·cm DI water | 18 MΩ·cm DI water |
| Pressure (psi) | 950 | 1200 |
| Number of sweeps | 5-7<br>(15-20 min/sweep) | |
| Sweep speed (in./min) | ~0.5 | 12 |
| Duration (hours) | 2-2.5 | 2 |
| Clean room class | 100 | 100 |

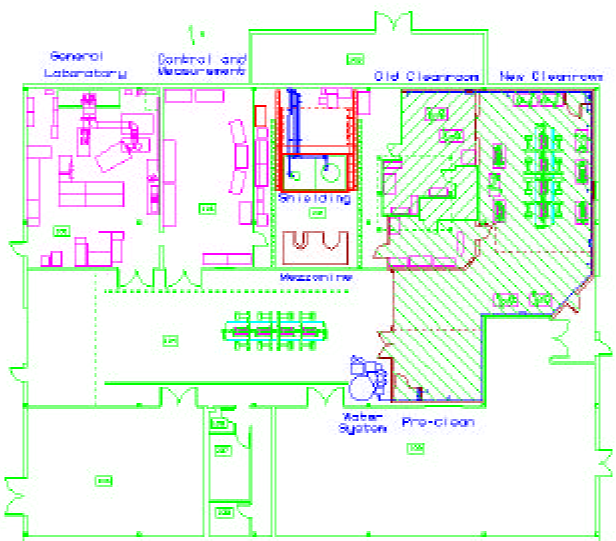

Fig. 1: SRF Lab at LANSCE [13].


Fig. 2: The cavity set on the insert.

## Test results

Figure 3 shows final $Q_0$-$E_{pk}$ curves of all the CERCA cavities, together with the APT specification. As one can see, all the cavities exceeded the APT specification with enough margins for stable operation. The result for cavity Eleanore is shown after helium processing, which lowered the low-field $Q_0$ (its initial value was close to cavity Ayako). It was found that the cavities measured at TJNAF (Germaine and Sylvia) showed higher low-field $Q_0$ by a factor of two. Investigation of this difference is underway, including the retesting of Germaine and Sylvia at LANL.

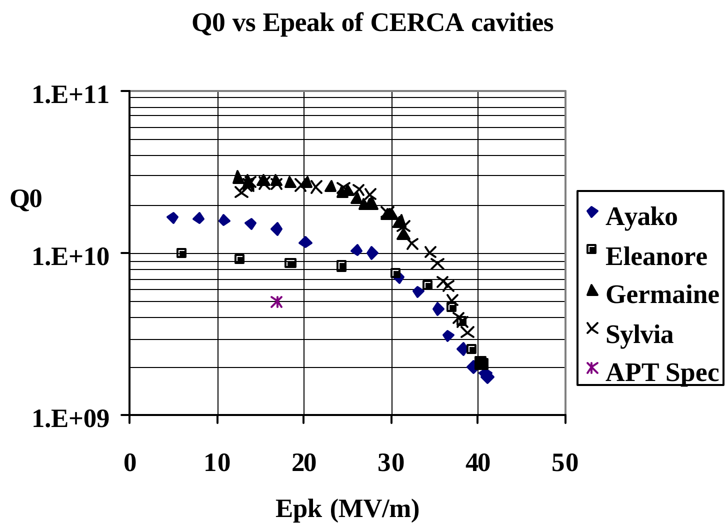


Fig. 3: Vertical test results at 2 K of 5-cell 700-MHz ($\beta$=0.64) cavities manufactured by CERCA. $E_{pk}/E_{acc}$=3.381.

Figure 4 shows $1/Q_0$ as a function of $E_{pk}^2$. The quality factor reciprocal $1/Q_0$ is an indicator of loss in the cavity. The linearly increasing part is attributed to the surface resistance, i.e., $G/Q_0$ (G: geometrical factor), and the non-linear part adds the contribution of the loss caused by field emission. As one can see, the non-linear part seems to start around $E_{pk}$=30 MV/m with all the

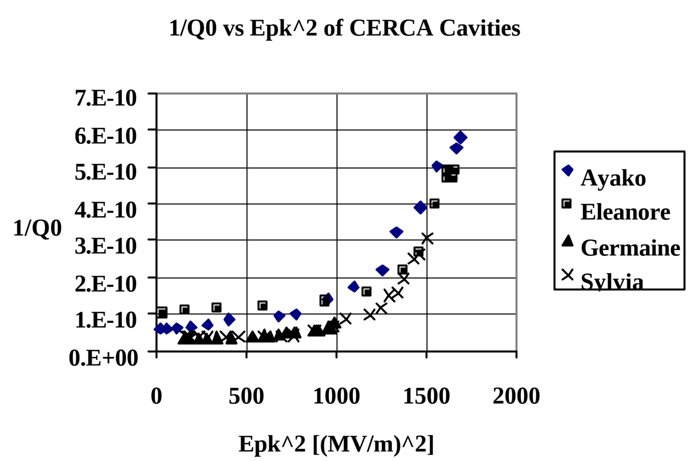


Fig. 4: $1/Q_0$ vs $E_{pk}^2$ of CERCA cavities.

cavities, indicating that there is some common feature of the structure.

Figure 5 shows the X-ray radiation monitored on the lid of the cryostat for cavities Ayako and Eleanore. This graph includes the data both before and after the helium processing for Eleanore. With helium processing the amount of X-rays at 20 to 30 MV/m was reduced, which lead to the final result shown in Fig. 3. The maximum field increased by about a factor of three in this case. As to Ayako, helium processing did not work very well (increased the field by about 3 MV/m). By repeating BCP twice (18 μm and 60 μm), we could get the curve shown in Fig. 1 without helium processing.

Table 4 shows the field enhancement factor calculated from the Fowler-Nordheim plot using the X-ray data of final Q-E curves.

The highest field was limited by available RF power for Ayako and Eleanor (~200W). With higher power we may have been able to process emission sites. We are planning to get a higher-power RF amplifier to try this.

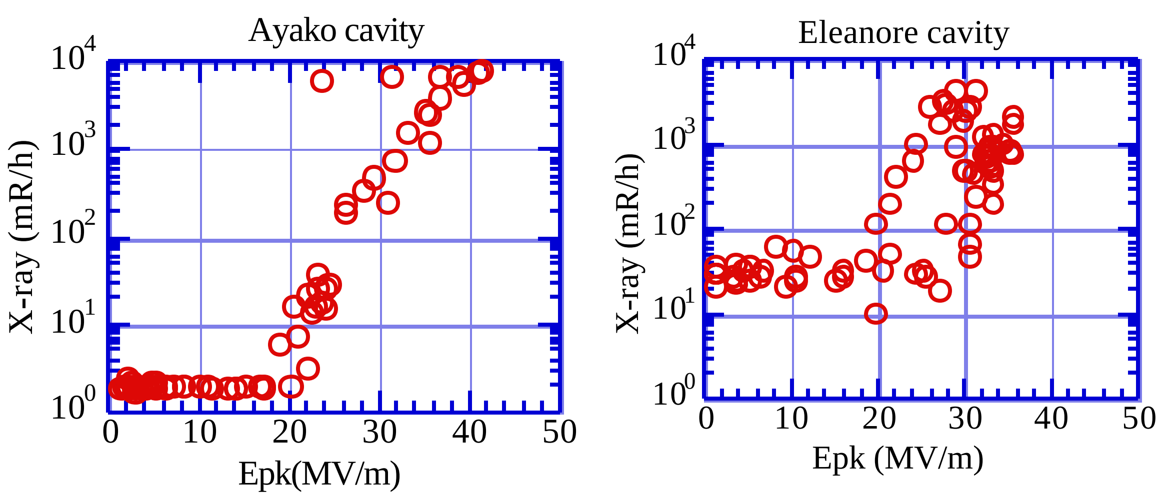


Fig. 5: Radiation monitored on the lid of cryostat as a function of peak electric field. The plot for the Eleanore cavity shows data both before and after helium processing. In the case of Eleanore, radiation decreased at 20 to 30 MV/m with helium processing. The radiation points at low fields in the Eleanore plot are faulty; they were at a similar level as for the Ayako cavity.

Table 4: Field enhancement factors calculated from radiation data.

| Cavity name | Field enhancement factor |
|---|---|
| Ayako | 583 |
| Eleanore | 441 |
| Germaine | - |
| Sylvia | 154 |

At TJNAF, the cavity Sylvia was tested again after the inner He vessel was welded to the end dishes in order to check for any degradation. Since the cavity was filled with air for a long period of time, a BCP of 5 μm was performed before test. The result showed no significant degradation, although it was limited by quench at 10.4 MV/m.

## Conclusion

The capability of producing superconducting cavities that meet requirements for APT was demonstrated. It seems possible to operate the machine at higher gradient than our present specification, which will lead to reduction of the number of cavities and associated components, i.e., cost.


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